The Solutions Network
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An Introduction to Technology Pathways Used in the Production of Transportation Biofuels

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Presentation Overview

- Background on transportation biofuel work performed by RTI for the Environmental Protection Agency (EPA)
- Description of selected resources and conversion technologies required to produce these biofuels
- Benefits/potential issues that may influence how transportation biofuels compete with fossil fuels

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Background on EPA Work

"Development of Input Data for Analyses of Potential Biofuels for Transportation"

Project for EPA's Air Pollution Prevention and Control Division

- **Stage 1**: RTI identified biofuel technology pathways (other than hydrogen production) for EPA

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Technology Pathway Defined

- **Input Resource** (e.g., energy crops such as corn)
- **Conversion Technology** (e.g., fermentation to ethanol using microbes)
- **Energy Carrier** (e.g., ethanol)
- **Demand Technology** (e.g., spark-ignition internal combustion engine)

Biofuel Pathways Explored for EPA

Input Resources	Conversion Technology	Products: Fuel (Energy Carrier)	Products: Potential Coproducts
Energy Crops OR Residues	Fermentation	Ethanol	Distillers Dried Grain w/Solubles Electricity
Energy Crops (Oil-Seed Crops) OR Animal Fats/Grease	Transesterification (Chemical Conversion)	Biodiesel	Glycerin Oil-Seed Meal
Energy Crops (Woody Crops)	Fisher-Tropsch (w/ Gasification)	Green Diesel	Electricity
Energy Crops (Woody Crops)	Thermochemical Conversion (w/ Gasification)	Methanol	Electricity

Background on EPA Work

"Development of Input Data for Analyses of Potential Biofuels for Transportation"

Project for EPA's Air Pollution Prevention and Control Division

- **Stage 1**: RTI identified biofuel technology pathways (other than hydrogen production) for EPA
- **Stage 2**: RTI collected data on pathways for EPA to use in modeling applications

Data Collected for EPA

Conversion Technologies:
- Investment costs
- Operating and maintenance costs
- Process efficiency
- Start year
- Technology lifetime

Input Resources:
- Market prices
- Production costs
- Transportation costs

EPA's Modeling Efforts — MARKAL

- Data from literature will be fed into the MARKAL (Market Allocation) model
- The model analyzes energy, economic, and environmental data for various technology pathways
- The model allows for assessment of pathways when key parameters are changed (e.g., resource availability, regulations, technology stage of development)
- MARKAL will help evaluate how alternative fuel technology pathways can compete over the long term (50 years) with fossil fuel production

Pathway #1: Ethanol via Fermentation

- Commercially well-established—in practice since the late 1970s
- Most common automotive biofuel conversion technology in the United States
- 7% of the U.S. corn crop used to produce ~1%–2% of the total automotive fuel supply
- ~2 billion gallons of ethanol produced annually from corn starch in the United States (3.2 B gal/yr produced from sugarcane in Brazil)
- Typically blended with gasoline (e.g., E85)
- Approximately 150 stations in 23 U.S. states

Ethanol via Fermentation – Resource Inputs

Starch Crops
- Corn
- Barley
- Wheat

Cellulosic Crops
- Grasses
- Trees

Crop Residues
- Corn stover

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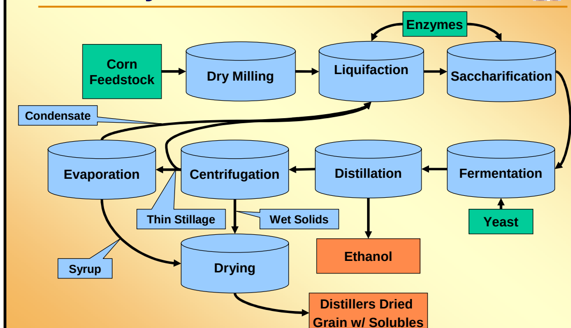
Ethanol via Fermentation with Dry-Milled Corn



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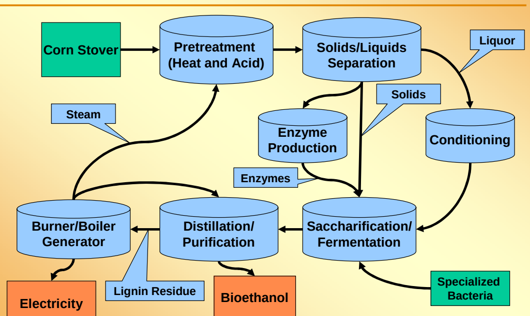
Ethanol via Fermentation with Corn Stover



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Ethanol via Fermentation Investment Costs

Facility Type	Capacity (gal/yr)	Investment Cost	Normalized Cost (per M-gal of capacity)	Source
Corn to Ethanol	25 M	$27.9 M	$1.1 M	McAloon et al., 2000
Corn Stover to Ethanol	25 M	$136.1 M	$5.4 M	McAloon et al., 2000
Corn Stover to Ethanol	295 M	$268.4 M	$0.9 M	Lynd, 1996

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Ethanol via Fermentation Production Costs

Pathway Type*	Feedstock Costs	Other Production Costs	Coproduct Credits	Total
Corn to Ethanol	$17.0 M/yr	$12.1 M/yr	–$7.1 M/yr (DDGS)	$22.0 M/yr
Corn Stover to Ethanol	$12.1 M/yr	$28 M/yr	– $2.8 M/yr (Electricity)	$37.3 M/yr

*Assumes a capacity of 25 M gal/yr of ethanol.
Source: McAloon et al. (2000)

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Ethanol via Fermentation Benefits

- Coproduct credits can help offset costs
- Potential use of waste products as resource input
- Ethanol use can reduce air pollution (ozone)
- Ethanol use can reduce dependence on toxic octane boosters such as benzene, toluene, and xylene
- Ethanol is less explosive than gasoline during an accident

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Ethanol via Fermentation Potential Issues

- Food crops are currently used as a resource input (ethical issue)
- Question of whether input crops could ever sustain pathway as a primary fuel provider
- Conventional gasoline engines can only operate on gasoline/ethanol blends up to 10% ethanol (E10)

Pathway #2: Biodiesel via Transesterification

- Used at the commercial scale in Europe since the late 1980s
- 60M–80M-gallon dedicated capacity in United States
- 22 U.S. states have public biodiesel stations
- Stand-alone vs. vertically integrated facilities

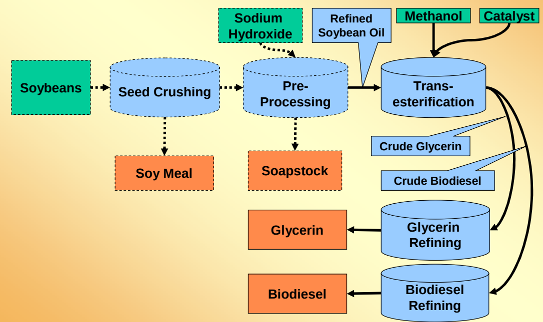
Biodiesel via Transesterification Resource Inputs

Vegetable Oils
- Soybean
- Rapeseed
- Canola

Waste Oils
- Yellow grease

Animal Fats
- Tallow
- Lard
- Poultry fat

Biodiesel via Transesterification with Soybeans



Biodiesel via Transesterification Investment Costs

Facility Type	Capacity (gal/yr)	Investment Cost	Normalized Cost (per M-gal of capacity)	Source
Stand-Alone Facility for Soybeans	13 M	$ 18.8 M	$1.4 M	AIM-AG et al., No date
Vertically Integrated Facility for Soybeans	13 M	$ 37.6 M	$2.9 M	AIM-AG et al., No date
Stand-Alone Facility for Vegetable Oil (Europe)	16.5 M	$35 M	$2.1 M	USDA, 2003b

Biodiesel via Transesterification Production Costs

- Stand-alone (13 M gal/yr): $14.2 M in feedstock costs (soybeans oil) + $5.7 M in other processing costs = ~$19.9 M/yr in production costs
- Stand-alone coproduct credit for glycerine of $7.4 M, so adjusted production costs are $12.5 M
- Vertically integrated facilities have higher operating costs than stand-alone because of added costs associated with seed crushing unit
- Vertically integrated facilities have additional coproduct credits (for meal and soapstock)
- One source indicated that production costs are potentially higher in Europe

Biodiesel via Transesterification Benefits

- Coproduct credits can offset costs
- Potential use of waste products as resource input
- Biodiesel is generally compatible with current storage and handling infrastructure
- Safer to handle—less combustible and less toxic than petro-diesel
- Reductions in most air pollutants

Biodiesel via Transesterification Potential Issues

- Use of biodiesel blends (B20), and especially pure biodiesel (B100), may require some engine modification to prevent performance and maintenance issues
- Increases in nitrogen oxide emissions

Pathway #3: Green Diesel via Fischer-Tropsch (F-T)

- Green diesel vs. biodiesel
- F-T process is used commercially to produce petroleum diesel from gasified coal or natural gas
- No commercial applications currently exist that use biosyngas
- The Netherlands is actively pursuing research in this area

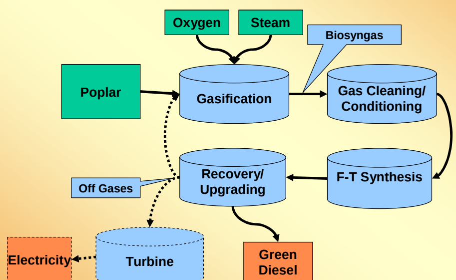
Green Diesel via F-T
Resource Inputs

Woody Crops
- Poplar
- Willow

Wood Wastes/Residues

Fossil Inputs (F T Diesel)
- Natural gas
- Coal

Green Diesel via F-T
with Poplar



Green Diesel via F-T
Investment/Production Costs

- Investment costs of $335 M for a ~29M-gal/yr plant
- Pretreatment, gasification, and gas-cleaning stages account for ~75% of total investment costs for an F-T plant with biomass gasification
- Feedstock costs (for poplar) of >$42 M/yr for a ~29M-gal/yr plant
- Other production costs of $22.2 M/yr to $23.9 M/yr for a ~29M-gal/yr plant
- Electricity credits could offset production costs
- Over the short term, production costs for green diesel appear to be about four times the cost of petroleum diesel

Green Diesel via F-T Benefits

- Electricity as a coproduct
- Potential use of waste products as resource input
- Generally compatible with current storage and handling infrastructure
- Safer to handle—less combustible and less toxic than petro-diesel
- Reductions in most air pollutants

Green Diesel via F-T Potential Issues

- Removing tar is currently the most critical step of the F-T pathway when using biosyngas
- Unproven commercially (stage-of-development issues)
- F-T green diesel may prove to be more expensive than methanol or hydrogen

Pathway #4: Methanol via Thermochemical Conversion

- Methanol (wood alcohol) as a chemical commodity vs. fuel
- Natural-gas-to-methanol (i.e., fossil fuel) plants well-established commercially
- 90 natural-gas-to-methanol plants worldwide (annual capacity of more than 11 B gallons)
- 18 methanol production facilities in the United States, with an annual capacity of up to 2.6 B gallons
- Biomass-to-methanol plants not yet commercial
- One source predicts commercial-scale biomass plants online by 2010

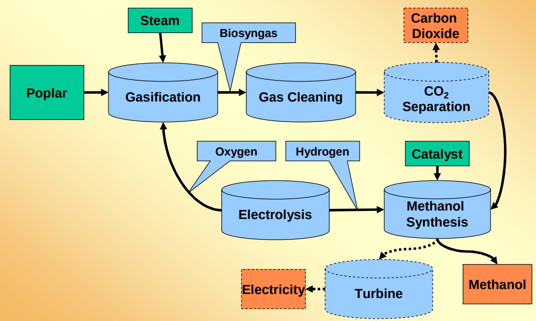
Methanol via Thermochemical Conversion

Woody Crops
- Poplar
- Willow

Wood Wastes/Residues

Fossil Inputs
- Natural gas
- Coal

Methanol via Thermochemical Conversion with Poplar



Methanol via Thermochemical Conv. – Investment/Prod. Costs

- Little cost data on biomass-to-methanol plants
- One source indicated capital costs of $15.4 M to $24 M for a plant with a capacity of 25–50 tons of methanol per day (depending on plant configuration)
- Capital costs are approximately 3 to 7 times higher than for natural-gas-to-methanol plants
- No data found for production costs

Methanol via Thermochemical Conversion – Benefits

- Electricity as a coproduct
- Potential use of waste products as resource input
- M85 vehicles produce 40% less CO and NOx vs. vehicles running on reformulated gasoline
- Methanol is less explosive than gasoline during an accident

Methanol via Thermochemical Conversion – Potential Issues

- Biomass-to-methanol process is unproven commercially (stage-of-development issues)
- Methanol fuel is not currently in widespread use
- Expense associated with retrofitting refueling stations for methanol
- High levels of formaldehyde in emissions

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